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RESEARCH ARTICLE

Monitoring of airborne asbestos fibers in an urban ambient air of Mashhad City, Iran: levels, spatial distribution and seasonal variations

Asiyeh Moteallemi[1] · **Masoud Minaei**[2] · **Masoumeh Tahmasbizadeh**[3,4] · **Saeid Fadaei**[3,4] · **Kazhal Masroor**[5] · **Farzad Fanaei**[6,7]

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Abstract

Asbestos, as with other pollutants in the air, has adverse effects on the health of human beings and animals. Today, the relationship between presence of asbestos fibers in the air breathed by humans and developing serious diseases such as lung cancer (asbestosis) and mesothelioma has been proven. The objectives of this study were to monitor the levels of asbestos fibers in ambient air of Mashhad, Iran during 2018, and to draw its Geographic Information System (GIS) distribution map for the city. In this descriptive study, 13 sampling points in Mashhad city were chosen. Sampling of asbestos was carried out for 3 hour during summer and winter at 2018. Sampling of asbestos was performed using MCE (Mixed Cellulose Ester) membrane filters (pour size 0.45 μm; diameter: 25 mm) and cassette holder and peripheral pump. The samples were the analyzed by the phase contrast microscopy (PCM) method (NIOSH7400). Also, to investigate the type of asbestos and for more accurate counting of fibers, Scanning Electron Microscopy (SEM) analysis was utilized. Meteorological parameter were recorded through portable devices. To draw the graphs, Excel, R and Arc GIS software were used. Results showed that the mean asbestos fiber concentrations were equal to 11.40 ± 2.14 and 14.38 ± 2.52 f/L in summer and winter, respectively. The maximum level of asbestos fiber was detected in the station of Baitolmoghaddas square by 26.64 ± 2.14 and 19.3 SEM f/L in winter and summer, respectively. High concentration of asbestos fiber observed in this study can be attributed to the heavy traffic, the presence of prominent industries in the vicinity of the study area, and topographic features. The results from this research recommends that suitable controlling policies should be regulated to reduce both ambient air asbestos and its adverse health endpoints in Mashhad.

Keywords Asbestos aibers · Ambient air · GIS, Mashhad City

✉ Farzad Fanaei
farzadfanaei37@gmail.com

[1] Department of Environmental Health Engineering, Torbat Jam Faculty of Medical Sciences, Torbat Jam, Iran

[2] Department of Geography, Ferdowsi University of Mashhad, Mashhad, Iran

[3] Department of Environmental Health Engineering, School of Health, Isfahan University of Medical Sciences, Isfahan, Iran

[4] Student Research Committee, School of Health, Isfahan University of Medical Sciences, Isfahan, Iran

[5] Department of Environmental Health Engineering, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran

[6] Department of Environmental Health Engineering, School of Public Health, Iran University of Medical Sciences, Tehran, Iran

[7] Student Research Committee, Iran University of Medical Sciences, Tehran, Iran

Introduction

Asbestos, as a solid pollutant is of a particular importance among airborne particles, and is referred to as a group of fibrous silicate minerals. The silicate minerals are divided into two groups: serpentine (Chrysolites) and amphibole [1]. Chrysolites or white asbestos are the main form of commercial asbestos utilized as a raw material in certain industries to produce the clutches, pads, and brake linings of automobiles [2]. These compounds are also extensively used in various industries such as Asbestos Cement (AC) pipes and sheets, vinyl asbestos floors, ventilation ducts, brakes and clutches, and electrical and thermal insulation materials [3–5]. In the last decades, some developed countries have prohibited the use of all kinds of asbestos [6]. However, asbestos products are still used in the industries meaning that its consumption is not restricted in our country, and AC plants like asbestos cement roofing slates

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approximately account for 94% of the overall national usage [7, 8]. Definitely, asbestos is carcinogenic to the humans and it has been classified into the Group I carcinogens by the International Agency for Research on Cancer (IARC) [9]. The exposure to asbestos fibers can cause severe health issues such as asbestosis, lung cancer, mesothelioma, and other respiratory diseases over time [2, 10]. The asbestos concentration in ambient air of rural regions has been reported to be 0.00001 f/mL; however, the asbestos fiber concentration in the ambient air of urban regions is about 10 times greater than that of villages [11]. The standard asbestos concentration in the ambient air is equal to 0.05 PCM f/L (2.2 SEM f/L) according to the World Health Organization (WHO) [12, 13]. It is difficult to identify and assess the structure, dimensions, and morphology of the asbestos fibers [14]. Hence, various instruments have been used so far to measure these fibers including the Scanning Electron Microscopy (SEM), Polarized Light Microscopy (PLM), and Phase Contrast Microscopy (PCM) [15, 16]. Given the lack of criteria to show the health risks related to asbestos exposure in Iran, SEM is the only technique available to measure the asbestos fibers among non-fibrous particles in the ambient air [17].

To date, several studies have been conducted to detect and measure the airborne asbestos fiber levels in the world. For instance, airborne asbestos fiber concentration has been reported as 0.47, 2–4, 0.2-5, and 4.6 f/L in urban areas of France [18], Canada [19], Germany, and Australia [20]. Also, the airborne asbestos fiber levels detected in urban regions of Iran such as Isfahan [14], Tehran [11], and Shiraz [2] were equal to 10.4, 14, and 12.21 f/L, respectively. A study conducted in Korea in 2004, average concentration of asbestos fibers was measured 0.62 f/L in urban and 67.86 f/L in rural areas [21].

Mashhad, as the second most populated city in Iran is located in the northeast of Iran with a population of more than 3 million people. Since the problem of air pollution needs more attention than ever before, identifying the share of air pollution in health consequences can be useful in many aspects, including programs to control air pollution, the economic costs of mortality, and so on. On the other hand, most of the studies in this city have focused on the chemical properties of PM particles, but there is no adequate evidence with regards to the asbestos concentration levels in the atmosphere of Mashhad and the associated health risk. Since; there is a need to measure this pollutant in the atmosphere of Mashhad. Therefore, this study was carried out to determine the spatio-seasonal distribution of asbestos fiber levels in the ambient air of Mashhad city.

Materials and methods

Site of study and sampling

Mashhad city with a population of more than Three million is the capital of Khorasan Razavi Province in Iran and it is one of the largest and the most beautiful cities in the world. Mashhad with an area of 351 km^2, one of the most important industrial cities in northeast Iran. This city surrounded by the mountains of Hezar Masjed and Binalood among many established industries. Its minimum and maximum height is 950 and 1150 m, respectively. Mashhad is located between longitude 59°35'E to 59°74´E and latitude 36°14'N to 36°48´N with a height of 1150 meters above sea level. The highest and lowest temperatures in the summer (warm and dry) and winter (cold and humid) are approximately by 43 and 23 °C, respectively [22].

This cross-sectional study was carried out during summer and winter in 2018 to determine the asbestos concentrations in Mashhad. A total number of 13 stations were selected for sampling based on the extent of traffic and deployment of emission sources. (Fig. 1) [23]. Sampling was carried out during the day at different times above the wind direction. The sampling points were selected at high traffic points of the city, close to the industrial town and inhabited areas to detect the asbestos fiber concentration in the ambient air. Additionally, sampling was done during summer and winter to investigate the effect of seasonal variations and meteorological parameters on the asbestos concentration. Totally, 26 samples were collected from all the stations. The sampling equipment used in this study was consisted of a high-volume peripheral pump (SKC MCE Flite, Sweden), Mixed Cellulose Ester (MCE) filter (MCE; 0.45 µm of pore size; 25 mm of diameter), and a holder filter with an open mouth (Conductive Polypropylene Cassette Blank, 3 sections, 25 mm, Black; Manufactured in SKC Inc., Sweden). Sampling was done for 3 hours with a flow rate of 8.5 l/min. The equipment was installed 160–180 cm above the ground level. (Fig. 2).

Preparation and examination of the samples

SEM analysis

The plates containing ester-cellulose filters were transferred to the laboratory for preparation and analysis. The asbestos fiber was identified in accordance with the method BS ISO14966; 2002, specified by the Asbestos International Association (AIA) [24]. For analyzing the samples, first the filter was attached to the pod holding the SEM sample by the copper bilateral glue. Then, it was fully coated by a thin layer of gold using a gold coating device in vacuum (EMITECH K450X, EM Technologies LTD, England). Next, the coated samples were detected by the Scanning Electron Microscope (SEM) (WEGA/TESCAN, Czech Republic, magnification of 500–2500). The tracked and counted fibers had a length and diameter higher than 5 and below than 3 µm, respectively, and the minimum length-to-diameter ratio was equal to 3:1. Energy-

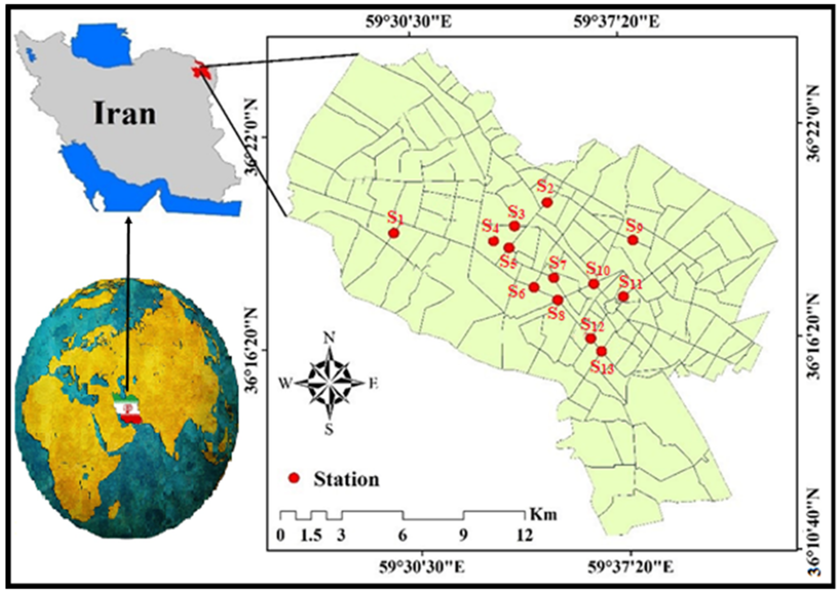


Fig. 1 Study area and the location of the stations

Dispersive X-ray Spectroscopy (EDXA) was used to detect the asbestos fibers from non-asbestos ones and to determine the fiber type. SEM detection sensitivity was estimated to be at a range of 0.0001 f/mlp. SEM results were calculated by the following formula [25]:

Fig. 2 Sampling Pilot

$$C_{SEM} = \frac{1000NA}{Vna}$$

where, N is the amount of counted fibers, A is the effective area of the filter (usually having a different color than the filter due to passage of air stream), which is about 385 mm^2 for the 25-mm filter, V is the sampling volume (L), n is the number of field levels in the counted images, and a is the calibrated area of each image (mm^2).

Spatial variation of asbestos

ArcGIS software version 10.3 (developed by the Environmental Systems Research Institute (ESRI) Company) was utilized in order to assess the spatial variation in the ambient asbestos fiber level. Inverse Distance Weighted (IDW) method was utilized after assessing various interpolation methods. IDW is among the most common interpolation methods used in various studies to determine the distribution of environmental pollutants such as heavy metals, particulate matters, Polycyclic Aromatic Hydrocarbons (PAHs), ozone, Polychlorinated Biphenyls (PCBs), and other pollutants. In the IDW method, each measurement was assigned to the reference point after weighting by the inverse of the distance using a point -based and typical local interpolation algorithm. IDW is represented by the following equation:

$$Z = \frac{\sum_{i=1}^{n} w_i Z_i}{\sum_{i=1}^{n} w_i} = \frac{\sum_{i=1}^{n} Z_i / D_i^p}{\sum_{i=1}^{n} 1 / D_i^P}$$

where, Z defines the interpolated value for a point with an unknown observed value, wi is the weighting function showing the relative importance of each individual control point Zi in the interpolation procedure, Zi is the observed value at control point i (i = 1,…., n), which is in the closest neighborhood of the interpolated point, and n is the total number of such points used in the interpolation [26, 27].

Statistical analysis

Data were analyzed using the SPSS software V.22. Spearman correlation coefficient method was used to study the association of fiber concentration with temperature and air humidity.

Results

Figures 3a, b, c, d show the results obtained from the sample analysis regarding determining the asbestos fiber concentration in the atmosphere of Mashhad. As presented in Figs. 2, 3, 4 and 5 and S_{11} (0.0266 f/mL) and S_3 (0.0243 f/mL) have the highest concentration of asbestos fiber, whereas the least concentration was observed at S_1 point (0.0051 f/mL). Besides stations 11 and 3, station 8 also had a high concentration of asbestos fibers. Also, the mean concentrations of these fibers were equal to 0.0114 and 0.0143 f/mL in the summer and winter, respectively. Comparing the asbestos fiber concentrations in different months of summer showed that the highest and lowest levels were in August and June by 0.0139 and 0.0097 f/mL, respectively (Table 1). In the winter, the maximum and minimum values were equal to 0.0171 and 0.0117 f/mL in February and December, respectively (Table 1). The results of qualitative analysis on the detected fibers showed that 78% of the detected fibers were asbestos and the others were detected as non-asbestos fibers. Figure 4 shows the results of SEM analysis coupled with EDX. As demonstrated in Fig. 4, the chemical composition of the fibers and types of asbestos fiber can be distinguished based on the EDX spectra. In general, the peaks related to the spectra of Si, Mg, and Ca can be attributed to the Thermolite [28]. The findings of the study on the type of asbestos fiber were congruent with our expectations. Figure 5 presents a comparison regarding the asbestos fiber levels in the summer and winter with the standard level recommended by WHO

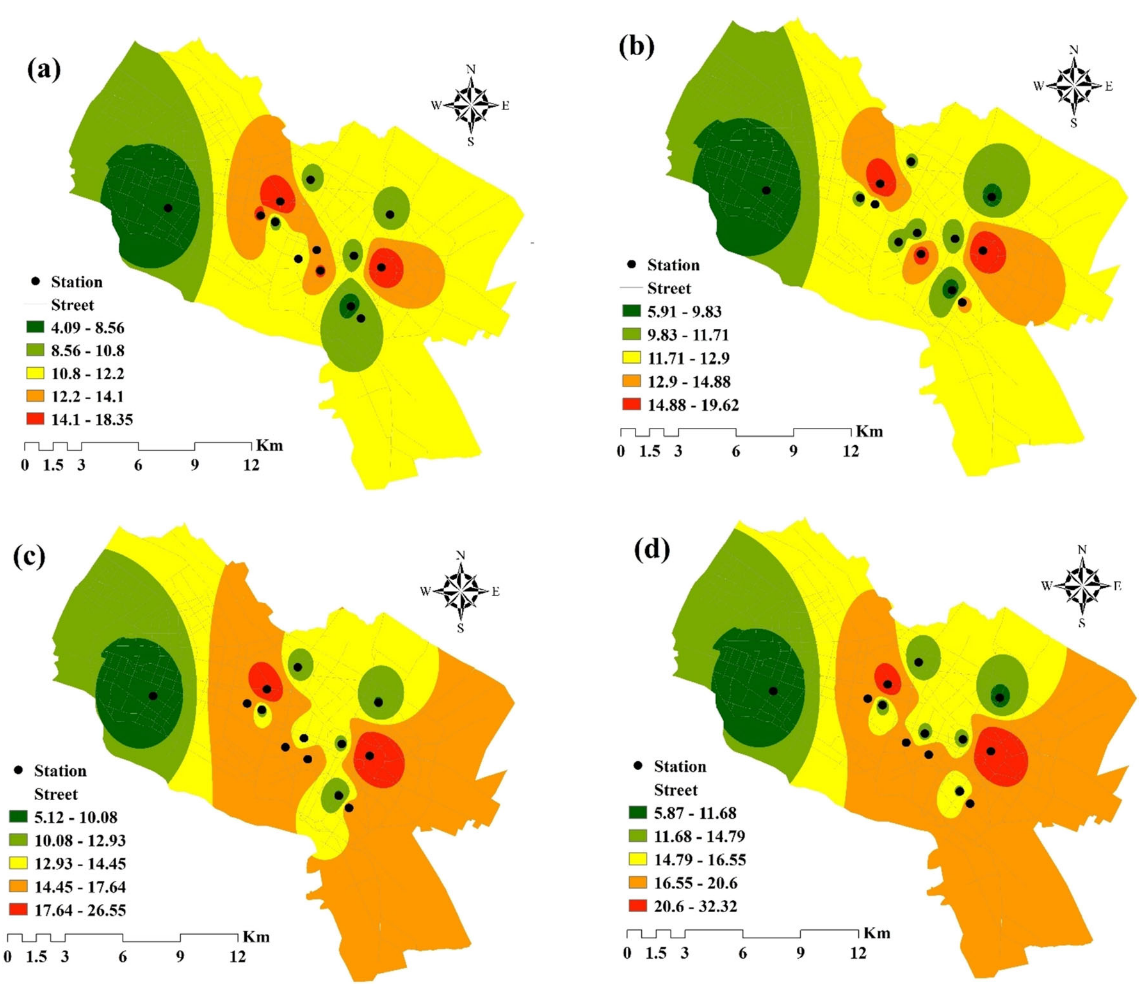


Fig. 3 Spatial distribution of the asbestos (**a**) mean in winter (**b**) maximum in winter (**c**) mean in summer and (**d**) maximum in summer

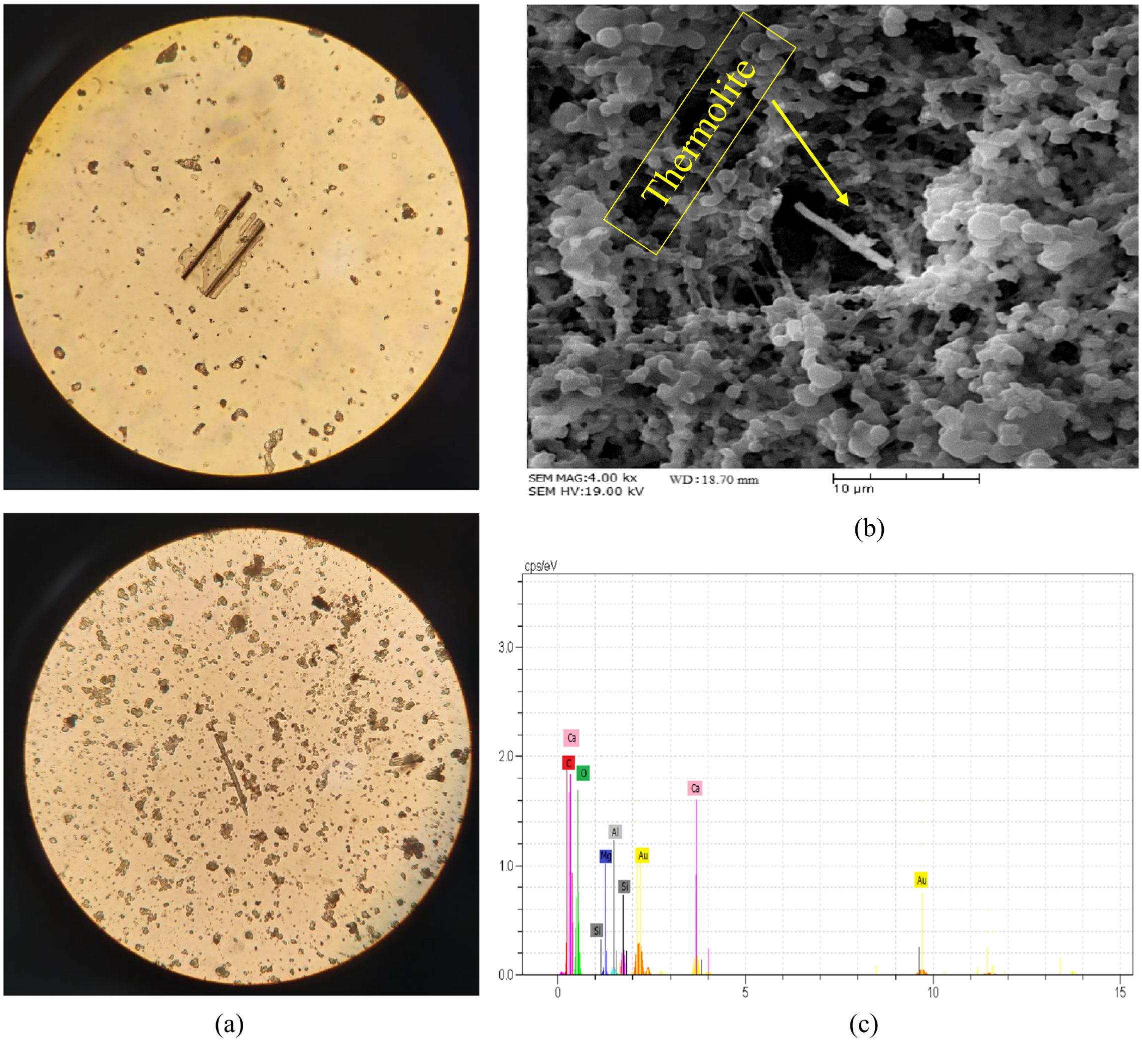
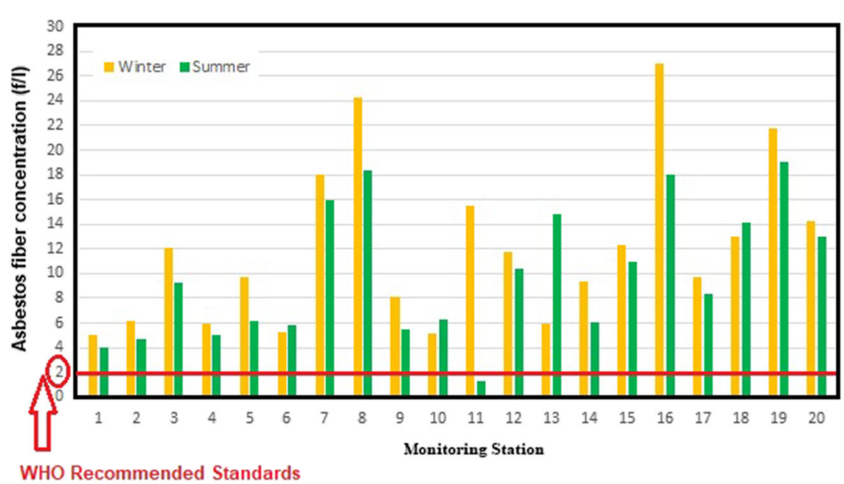


Fig. 4 (**a**) Asbestos sample under a microscope, (**b**) Thermolite lobe image in the air sample under the SEM microscope and (**c**) EDX

(WHO, 1986) (according to the SEM analysis) in the ambient air. As depicted in Fig. 5, the asbestos fiber concentrations were greater than the WHO standard level in the majority of stations and in both seasons. Results of the statistical test (t-test) indicated a significant relationship between the asbestos fiber concentrations in the summer and winter with the WHO standard level ($p < 0.0001$).

Fig. 5 The variations of asbestos fiber concentrations in sampling points and their comparison with WHO recommended standard



Discussion

Figures 3a, b, c and d present the asbestos fiber concentration in the atmosphere of Mashhad. Since, S_{11} and S_3 are situated in the main heavy-traffic area of Mashhad, the high levels of asbestos fibers can be attributed to the automobiles, and their apparatus (brake pad, clutch pad, washer, and glues) originally made of asbestos and also the presence of hotels, commercial buildings, and offices in both regions. Also, in the S_8, the sequential application of brake and clutch in the automobiles as a result of heavy traffic or old and narrow streets in this region further increases the release of asbestos fibers into the ambient air [29]. Other factors such as repairing and constructing the old houses also can contribute to the increased concentrations of asbestos fibers in this area [25].on the other hand, asbestos fiber in winter due to more fuel consumption of cars, the use of heating system in cars as well as in homes and the presence of inversion in the air, can be high concentration. Kakouei, in a study conducted in Tehran (capital of Iran) showed that the highest concentration of asbestos was equal to 0.016 f/mL, which was higher than the standard limit and only had a difference of 0.0106 f/L with Mashhad (0.0266 f/mL) highlighting the crisis in Mashhad in terms of traffic load, the increase in the asbestos fiber levels, and consequently air pollution [13]. A previous research conducted in three regions of Italy showed that the mean concentration of asbestos fiber was equal to 0.56 SEM f/L indicating that the citizens of Italy were about 13.7 times more likely to be exposed to the risks associated with asbestos particles compared to the people in the European countries [30, 31]. High level of asbestos fibers in the studied stations may be due to the topographic position of Mashhad city (being surrounded by the Hezar Masjed Mountains in the northeast and Binalood Mountains in the west and southwest), the existence of numerous industries, especially the cement manufacturing plant around the city, as well as the traffic condition of this city, which is consistent with the study performed in Tehran where the mean concentration of asbestos fibers was also higher in the winter than the other seasons [11]. Lim et al., reported that the asbestos fiber concentrations were equal to 67.86 and 0.62 f/L in the rural and urban areas of South Korea, respectively [21]. Comparing the asbestos fiber concentrations in ambient air of Iran with developed countries showed lower concentrations in the developed countries than Iran, which is due to the prohibition of asbestos application and the decrease in the consumption of asbestos products in the past years [14]. Asbestos is still used in the developing countries, like Iran [32]. It has been reported that approximately 2000 metric tons of asbestos were only consumed for production of clutch and brake in 2007 [33].

According to the results of SEM analysis on the high - traffic areas in S_{11} and S_3, Thermolite fiber was the most common type of fiber observed at these stations. It is noteworthy that, Thermolite fibers are used for fabricating the brake pads and building the insulators, which were frequently detected in high-traffic and residential areas of the city. Polyvinyl Alcohol (PVA), cellulose, Polyacrylonitrile (PAN), glass fibers, and aramid fibers are the alternatives for asbestos fibers that can be used in the construction industries to reduce the risk of exposure to asbestos fibers [34]. Also, it is recommended to use the alternative materials such as ceramic, metallic ,or organic material disks for example, carbon, fiberglass, or rubber in production of clutch and brake disk [33, 35].

Comparing the asbestos fiber concentrations with the WHO standard level showed similar results to other studies. For example, the results of a study conducted in Tehran showed that these values were greater than the WHO standard level during different seasons as reported in the studies by Mokhtari et al., and Taghizadeh et al. [11, 32, 36]. In addition, in this study, the level of asbestos fiber was extremely high compared to that of other parts of the world and Iran.

Table 1 Average of concentration asbestos fibers in different months of summer and winter

	Number of samples	Average	Wind Speed	Temperature	Reality Humidity
Summer					
June	13	9.79	8	28.1	28
July	13	10.52	8.1	27	26.3
August	13	13.91	7.2	25.2	28.5
Total	39	11.4	7.76	26.7	27.6
Winter					
December	13	11.37	4.8	4.9	61.8
January	13	14.6	13.4	2.1	80.6
February	13	17.18	5.6	4.7	61.7
Total	39	14.38	7.93	3.9	68.3

Finally, the meteorological parameters related to the sampling stations such as temperature, mean velocity of wind, and humidity were recorded during the sampling period. Results of the statistical tests revealed no significant association between the meteorological parameters and asbestos concentration and they were not influenced by these variations ($p > 0.05$, $r < 0.2$), which is similar to the results of other studies [32].

Conclusions

In general, results of the present study indicated that the asbestos fiber concentrations were higher in all the sampling stations than the normal standard level recommended by the WHO. This could be attributed to the large number of commercial buildings and hotels in the central regions of the study area (Mashhad) causing a heavy traffic jam. Given the high concentrations of asbestos fiber, there is a potential risk to the health of various occupational groups especially the traffic police. Controlling the traffic, replacing the asbestos with alternatives, transferring the industries to more distant areas, the expansion of green spaces and subway lines in the areas with the highest traffic load, as well as cultivation of the plants and encouragement of the people to use the public transport can have significant effects on reducing the concentration of asbestos fibers in this area.

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Compliance with ethical standards

Conflict of interest The authors of this article declare that they have no conflict of interests.

Ethical considerations The authors of this article have covered all the ethical points, including non-plagiarism, duplicate publishing, data distortion, and data creation in this article.

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